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3 **Life history characteristics of a potential invasive Ponto-Caspian goby, *Neogobius***
4 ***fluviatilis* in natural lakes from its native range (Black Sea region of Turkey)**

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6 Uğur Karakuş^A, Nildeniz Top^A, Erdi Gökhan Tepeköy^A, John Robert Britton^C, Ali Serhan
7 Tarkan^{A, B}

8
9 ^AFaculty of Fisheries, Muğla Sıtkı Koçman University, Muğla, Turkey

10 ^BDepartment of Ecology and Vertebrate Zoology, Faculty of Biology and Environmental
11 Protection, University of Łódź, Poland. Email: serhantarkan@gmail.com

12 ^CDepartment of Life and Environmental Sciences, Faculty of Science and Technology,
13 Bournemouth University, BH12 5BB, United Kingdom

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15 **Running Title:** Life history traits of *Neogobius fluviatilis*

1

2 **Abstract**

3

4 To fill the gap in and provide baseline knowledge for developing increased understandings
5 of the factors driving the invasiveness of the Ponto-Caspian gobiid *Neogobius fluviatilis*,
6 their life history traits (as somatic growth and reproduction) were studied in three natural
7 freshwater lakes in its native range. These populations were characterised by slow somatic
8 growth rates, being the slowest reported across all of their native and non-native ranges.
9 Ages were recorded to seven years old. Across the three lakes, there was considerable
10 variability in their sex ratios and reproductive traits (including length at maturity and
11 fecundity at length and age), revealing considerable inter-population variability. These data
12 thus suggest *N. fluviatilis* has considerable plasticity in the expression of their life history
13 traits, with this plasticity argued as a key factor in facilitating their ability to establish and
14 invade new waters following introductions.

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17 **Additional keywords:** Monkey goby, alien, age, egg size, shallow lakes

1 **Introduction**

2 Biological invasions are pervasive components of global environmental change that are
3 also important factors associated with biodiversity loss (Simberloff *et al.* 2013).
4 Understanding the process by which non-native species establish populations and invade is
5 important for invasion risk assessments and subsequent management actions (Gozlan *et al.*
6 2010; Copp *et al.* 2016). This understanding is facilitated when there is extant knowledge
7 on the biology and ecology of invaders in their native range (Copp *et al.* 2005), such as the
8 extent of plasticity in their life history traits (Ribeiro *et al.* 2008). Indeed, high plasticity in
9 the expression of life history traits tends to be a common trait of many globally invaders
10 (Davidson *et al.* 2011), including many invasive fishes (Gozlan *et al.* 2010).

11 An example of a potential invasive fish is the monkey goby *Neogobius fluviatilis*
12 (Pallas, 1814). A member of the family Gobiidae, one of the largest fish families
13 comprising more than 2,000 species and over 200 genera (Patzner *et al.* 2011), it is a
14 benthic species that inhabits a range of environments (from near-shore marine to brackish
15 and freshwater) (Thacker and Roje 2011). An omnivorous fish, whilst larger individuals
16 can be piscivorous, their diet generally consists of invertebrates and, occasionally,
17 planktonic algae (Jakšić *et al.* 2016; Tarkan *et al.* 2018). Their lifespan is reported up to
18 five years, with individuals tending to live longer in warmer waters (Sasi and Berber
19 2010).

20 Although *N. fluviatilis* has negligible economic value (Çınar *et al.* 2013), their
21 ecological significance can be substantial in invaded systems via their role as both novel
22 predators and prey (Piria *et al.* 2016a). This is important given that it has invaded many
23 European freshwater ecosystems (Copp *et al.* 2005; Grabowska *et al.* 2009; Jakovlić *et al.*
24 2015) through ‘stepping-stone’ dispersal via ballast water, followed by dispersal within
25 countries and basins through recreational sailing and angling pathways, as well as natural
26 dispersal (Grabowska *et al.* 2009; Jakovlić *et al.* 2015). It has been predicted that
27 compared to other Ponto-Caspian gobies (e.g. *Neogobius melanostomus*, *Ponticola*
28 *kessleri*), the natural dispersal of *N. fluviatilis* would be slow (Čáková *et al.* 2008),
29 potentially enabling management actions to slow this further (Britton *et al.* 2011).
30 However, invasion risk assessments (e.g. AS-ISK, Copp *et al.* 2016) have predicted the
31 species has potentially high invasiveness in Belarus (Matsistky *et al.* 2010), Iberia
32 (Almeida *et al.* 2013) and Croatia (Piria *et al.* 2016b), and moderately high invasion
33 potential in the Balkans (Simonović *et al.* 2013) and Finland (Puntila *et al.* 2013). In North

1 America, the species is listed as one of five potential high-impact non-native species in the
2 Great Lakes (Pagnucco *et al.* 2015). Their biological traits, including an extended
3 spawning period and high parental investment in reproduction (e.g. nest construction,
4 parental care) (Grabowska and Grabowski 2005), allied with their broad environmental
5 tolerances, phenotypic plasticity and opportunistic feeding (Kakareko *et al.* 2005; Čápková
6 *et al.* 2008; Grabowska *et al.* 2009), have been hypothesised as facilitating their invasion
7 success. Nevertheless, to date, there have been no reports of their invasive populations
8 resulting in ecological impacts (e.g. Jakšić *et al.* 2016; Piria *et al.* 2016b).

9 Comparative ecological data for non-native fishes between their native and invasive
10 ranges can assist developing understandings of the ecological drivers of successful
11 invasions (e.g. Britton *et al.* 2010; Oyugi *et al.* 2011). However, these comparisons are
12 rarely completed, especially for Ponto-Caspian gobies. Moreover, the ecology of *N.*
13 *fluviatilis* in freshwater environments has been poorly studied in both their native
14 (Sasi and Berber 2010; Konečná and Jurajda 2012) and non-native ranges (Plachá *et al.*
15 2010), although there are some available old literature on estuarine and marine populations
16 in their native range (Trifonov 1955; Biľko 1965; Smirnov 1986). In their native Turkish
17 range, only a single study is available on their growth and mortality (Lake Manyas; Sasi
18 and Berber 2010), despite them being noted more widely in ichthyofaunal and length-
19 weight relationship reports (e.g. İlhan *et al.* 2012). This means that the invasion risk
20 assessments and risk-based management of *N. fluviatilis* are poorly informed regarding
21 native life history traits, potentially leading to weak predictive power (Gozlan *et al.* 2010;
22 Britton *et al.* 2011). Consequently, the aim here was to quantify a suite of ecological and
23 biological characteristics of *N. fluviatilis* across three lakes in their native range and across
24 a gradient of environmental characters. Objectives were to: 1) assess age, growth and
25 reproduction of native *N. fluviatilis* from three large natural lakes; 2) use meta-analyses to
26 compare data from different locations; and 3) evaluate these results in the context of the
27 potential invasiveness of *N. fluviatilis* and the commensurate management actions for
28 minimising their invasions.

30 **Materials and methods**

31 *Study sites*

32 Three natural lakes (Manyas, Uluabat and Sapanca) located in the Marmara Region (north-
33 west of Anatolia, Turkey) were sampled for *N. fluviatilis* (Fig. 1). The main morphological

1 and physico-chemical characteristics of the lakes are summarized in Table 1. All of the
2 lakes had a rich ichthyofauna dominated by cyprinid fishes (Geldiay and Balık 2009), but
3 with other native gobiids also present: *Proterorhinus semilunaris* and *Knipowitchia*
4 *caucasica* in varying abundances. Some piscivores, such as *Esox lucius* and *Silurus glanis*,
5 and non-native species such as *Carassius gibelio*, *Lepomis gibbosus* and *Gambusia*
6 *holbrooki*, also exist in the lakes. As *N. fluviatilis* has been recorded in all ichthyofaunal
7 studies of the lakes (e.g. Numann 1958) then it is considered native. As all of the lakes
8 have been isolated from neighbouring ecosystems (e.g. by the Sea of Marmara), then the
9 populations were considered as genetically isolated.

10 Lake Manyas is a shallow-turbid lake that is an important RAMSAR site, especially for
11 a breeding site for migratory water birds (Albay and Akçaalan 2003). Seasonal water level
12 fluctuations of 1 to 2 m occur naturally, but are exacerbated by irrigation (Karafistan and
13 Arik-Colakoglu 2005). The lake has rich biodiversity, including more than twenty fish
14 species, plus fauna including otters, crayfish, water snakes, turtles, salamanders and frogs
15 (Albay and Akçaalan 2008). The investigated area of the lake for *N. fluviatilis* has 1.5 m
16 average depth and a large littoral region usually with muddy-sandy bottom and some large
17 rocks, and is surrounded by agricultural land.

18 Lake Sapanca is a moderately deep (elevation varies between about 31 to x 33 m) lake,
19 which is fed by several small streams and ground waters. Steep mountain streams that are
20 located to the south deposit large quantities of coarse gravel and rocks into the lake. The
21 catchment area is largely agricultural, with the lake used as a potable water source and has
22 supported important industries in the past (Arman *et al.* 2009). The lake now suffers from
23 large water level fluctuations and algal blooms, with drought and high water abstraction
24 resulting in dramatic water level reductions in 2013 and 2014. This reduced the water level
25 more than 3 m lower than the lake's critical hydrological threshold value (i.e. 29.98 m)
26 (WWF 2015). The low lake level affected the littoral areas where the fish samples were
27 collected, impacting catches of *N. fluviatilis*, with their absence in samples collected in
28 August and November 2014. Since 2015, water levels have returned to more normal levels
29 due high winter rainfall.

30 Lake Uluabat is a shallow eutrophic lake with seven small islands that also has
31 RAMSAR designation due to its high diversity of migratory water birds (Magnin and
32 Yarar 1997). Whilst the lake is used for fish production and irrigation, domestic and
33 industrial waste discharges negatively affect its water quality (Arslan *et al.* 2010). The
34 littoral areas have high coverage of submerged plants and the lake supports around 20

1 freshwater fish species (Çınar *et al.* 2013). Samples of *N. fluviatilis* were collected from
2 the littoral in areas of substrates of fine sand and organic mud, and with some cover of
3 emergent and submerged macrophytes.

4 *Sample collection and processing*

6 Sampling was completed using electrofishing (SAMUS-725G) between August 2014 and
7 January 2016 on a quarterly basis: August (summer), November (autumn), January
8 (winter) and April/ May (spring). At each lake, focus was in the littoral areas with stony/
9 rocky substrates, with each sampled area being approximately 200 m long and up to 1.5 m
10 in depth. Due to the low water levels of Lake Sapanca, no *N. fluviatilis* specimens were
11 captured in August and November 2014, whereas specimens were present in all samples
12 collected at the other lakes. On each sampling occasion, the lakes were all sampled in a
13 period of 4 to 5 days. In all cases, nesting (black) males were not included in subsequent
14 analyses due to their low number and potential to bias analyses. Following fish capture,
15 individuals were identified to species, with *N. fluviatilis* euthanized (anaesthetic overdose;
16 2-phenoxyethanol) and transported to the laboratory in a slurry of iced water.

17 In the laboratory, the fish were defrosted, measured (total length (TL), to 1 mm) and
18 weighed (W; to 0.1 g). Scale samples were then taken for ageing (from the area between
19 lateral line and dorsal fin) and then the gonads were removed for sex determination.
20 Females with ovaries containing yolked eggs were classified as mature, and those with
21 non-yolked or indistinguishable eggs were classified as immature; males with clearly
22 distinguishable testes were classed as mature. All ovaries were weighed (to 0.001 g), with
23 sub-samples taken from the anterior, middle, and posterior portions of each ovarian lobe
24 and sub-samples were fixed in 3.6% buffered formaldehyde.

25 The individual ages of all *N. fluviatilis* specimens were determined by counting true
26 annuli (after Vilizzi *et al.* 2013) by using scale impressions on acetate strips (10 scales for
27 each specimen) and read on a micro-projector (magnification: $\times 48$). The ages were
28 derived independently by two interpreters on two occasion without biological knowledge
29 of fish. Regenerated scales were excluded from analyses (7.3 % of all fish). Measurements
30 were taken of the total scale radius and distances from the scale focus to each annulus (as
31 the smallest distance between the points; Bagenal and Tesch 1978). Fecundity and egg
32 diameter were determined for 60 fish per lake (30 in spring and 30 in summer) from ovary
33 sub-samples collected in spring and summer using a stereomicroscope. Egg diameter was

1 determined by the measurement of 50 randomly-chosen oocytes per female using an ocular
2 micro-meter.

3 4 *Data analysis*

5 Lengths-at-age were determined by back-calculation using the Fraser-Lee equation
6 (Francis 1990): $L_t = c + (TL_c - c)(S_t / R)$, where L_t is TL when annulus t was formed, TL_c
7 is TL at capture, S_t is the distance from scale focus to the annulus t , R is scale radius, and c
8 is the intercept on the length axis from the linear relationship of TL versus scale radius (TL
9 $= 12.42 \times R + 17.42$, $r^2 = 0.56$, $P < 0.01$; $n = 211$). This c value (17.42 mm) was used as a
10 fixed body-scale intercept to reduce bias due to differences in the size distribution. The
11 length-weight relationship (WL) of *N. fluviatilis* of each lake was determined from $W =$
12 aTL^b , where a and b are the regression parameters, with the 95% confidence limits of b
13 used to indicate deviation from $b = 3.0$. Fitting of WL relationships was in R v.3.4.0 using
14 libraries 'FSA' and 'nlstools' (Ogle, 2017).

15 The literature review was done by using Web of Science, and supplemented by Google
16 Scholar, starting with the species name ('*Neogobius fluviatilis*') and life history traits 'age',
17 'growth', 'spawning', 'reproduction', 'age at maturity', 'length at maturity', 'fecundity'
18 and their combinations. To compare the growth data with literature values, two methods
19 were used. Firstly, the von Bertalanffy growth function (VBGF) was used, where: $TL =$
20 $TL_{\infty} (1 - e^{(-K (age - t_0)})}$ where TL_{∞} is the asymptotic TL, K the Brody growth coefficient
21 (years^{-1}), and t_0 the age (year) of the fish at 0 mm TL (Ricker 1975). Note that in the lake
22 samples, the back-calculated lengths at ages of males and females could not be modelled
23 separately by VBGF due to minimum sample size requirements, so their data were
24 combined. As per Vilizzi *et al.* (2015), comparisons between groups for VBGF was
25 completed by hierarchical fitting eight models in total (Beverton-Holt parameterisation
26 only): i) a general model with separate parameter estimates for each group (e.g. $TL_{\infty 1} \neq$
27 $TL_{\infty 2}$, $K_1 \neq K_2$, $t_{01} \neq t_{02}$; where 1 and 2 are the two different groups in the comparison); ii)
28 three models with one parameter in common between groups (e.g. TL_{∞} , $K_1 \neq K_2$, $t_{01} \neq t_{02}$;
29 $TL_{\infty 1} \neq TL_{\infty 2}$, K , $t_{01} \neq t_{02}$; $TL_{\infty 1} \neq TL_{\infty 2}$, $K_1 \neq K_2$, t_0); iii) three models with two parameters
30 in common between groups (e.g. TL_{∞} , K , $t_{01} \neq t_{02}$; TL_{∞} , $K_1 \neq K_2$, t_0 ; $TL_{\infty 1} \neq TL_{\infty 2}$, K , t_0);
31 and iv) one common model with the same parameter estimates for all groups (i.e. TL_{∞} , K ,
32 t_0). To select the best fitting model both the Akaike (AIC) and Bayesian Information
33 Criterion (BIC) were computed with preference given to BIC in case of major disparity of

1 outcomes for reasons of model parsimony (i.e. fewer parameters) (Burnham and Anderson
 2 2003). Model fitting was performed in R v3.4.0 (R Core Team 2017) using package ‘FSA’
 3 v0.8.16 (Ogle 2017), with 1000 bootstrap confidence interval estimates of the parameters.
 4 For the comparison, each *N. fluviatilis* population for which a VBGF was originally
 5 provided, the index of growth performance Φ (Pauly & Munro 1984): $\Phi = \text{Log}K + 2 \text{Log}$
 6 TL_∞ was computed. Then, to compare the relative growth performance of *N. fluviatilis*
 7 across all locations (native and non-native range), a relative growth index was calculated
 8 (*GI*, %; Hickley and Dexter 1979). After using the Walford (1946) method to obtain a
 9 straight line by plotting TL at mean age (*n*) of all specimens against TL at age (*n* + 1), the
 10 *GI* was calculated as the mean value of the growth in each age class of *N. fluviatilis* for a
 11 certain location relative to TLs at age, obtained using the formula $l_n = L_\infty (1 - k^n)$ where L_∞
 12 $= l_i / (1 - k)$; l_i = intercept; l_n = TL at age *n*; k = slope of the Walford plot (after Hickley and
 13 Dexter 1979): $GI = \sum \text{TL}_{oi} / \text{TL}_{ri} \times 100$, where TL_{oi} and TL_{ri} are the observed and reference
 14 mean total length, respectively, of the *N. fluviatilis* at age *i*. Only the first three age classes
 15 (i.e. comparable ages) of each population were used in the calculations, as high levels of
 16 variability in the estimated length at older ages in the reviewed dataset was detected,
 17 suggesting some potential issues of ageing accuracy and precision (Beamish and
 18 MacFarlane 1983).

19 Mean age at maturity was calculated from the percentage of mature males and females
 20 in each age-class using the formula of DeMaster (1978):

$$\alpha = \sum_{x=0}^w (x) [f(x) - f(x-1)]$$

21
 22
 23 where α is the mean age of maturity (AaM), *x* is the age in years, $f(x)$ is the proportion of
 24 fish mature at age *x*, and *w* is the maximum age in the sample. A modified version of this
 25 formula (10 mm TL intervals in place of age-classes; Trippel and Harvey 1987) was used
 26 to calculate mean TL at maturity (LaM). Absolute fecundity (AF) was estimated
 27 gravimetrically as: $AF = W_G \times D$, where W_G is the weight of ovary, and *D* is the density of
 28 number of mature oocytes per g of ovarian tissue. Relative fecundity (RF = number of
 29 oocytes g^{-1} of female) was calculated as $RF = AF / W_T$ (Bagenal and Tesch 1978). The
 30 gonado-somatic index (GSI) was calculated from both males and females for each
 31 population as: $GSI = (W_G / W_T) \times 100$ (Wootton, 1990).
 32
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 34

1 *Statistical analyses*

2 Differences in the sex ratio between male-to-female from 1:1 was tested using chi-squared
3 (χ^2) goodness of fit. Comparisons in TL, weight, *b*, GSI, absolute and relative fecundity of
4 *N. fluviatilis* amongst the lakes, age classes and between sexes of the species were made by
5 permutational univariate analysis of variance (PERANOVA), based on a one fixed-factor
6 design in each case following normalisation of the data and using a Euclidean dissimilarity
7 measure. Data was used to obtain a distance matrix, which was subjected to 9999
8 permutations of the raw data and tested for significance (PERMANOVA+ v1.0.1 for
9 PRIMER v6: Anderson *et al.* 2008). The advantage of PERANOVA over traditional
10 parametric analysis of variance is that the stringent assumptions of normality and
11 homoscedasticity in the data typical of fully parametric analysis of variance (ANOVA),
12 and which prove very often unrealistic when dealing with real-world ecological data sets,
13 are substantially relaxed (Anderson and Robinson 2001). For comparative purposes, total
14 length (TL, mm) was taken as the reference length measurement and whenever required,
15 mean length at age (LAA) values that were expressed as standard length (SL, mm) across
16 all reviewed studies were converted to TL using following species-specific conservation
17 factor from SL (Froese and Pauly 2017): $SL = 0.841 TL$.

18

19 **Results**

20

21 *Sex ratio, sample and body size*

22 In total, 575 *N. fluviatilis* were collected from Lake Manyas, 223 specimens from Lake
23 Uluabat and 152 specimens from Lake Sapanca (Table 2). Mean total length (# =
24 permutational, $F_{2,946}^{\#} = 199.76$, $P < 0.01$) and weight ($F_{2,946}^{\#} = 411.55$, $P < 0.01$) varied
25 significantly amongst the lakes, with *N. fluviatilis* in Lake Manyas significantly larger than
26 that in Lake Uluabat (for TL: $t^{\#} = 15.56$, $P < 0.01$; for W: $t^{\#} = 24.80$, $P < 0.01$) and Lake
27 Sapanca (for TL: $t^{\#} = 12.87$, $P < 0.01$; for W: $t^{\#} = 14.73$, $P < 0.01$). *N. fluviatilis* in Lake
28 Uluabat was then significantly larger than that in Lake Sapanca (for TL: $t^{\#} = 12.05$, $P <$
29 0.01 ; for W: $t^{\#} = 9.67$, $P < 0.01$). In Lake Manyas females were significantly larger than
30 males ($F_{1,174}^{\#} = 234.19$, $P < 0.01$), whereas the opposite was true in Lake Uluabat ($F_{1,303}^{\#} =$
31 63.55 , $P < 0.01$). In Lake Sapanca, there was no difference in mean TL between males and
32 females ($F_{1,125}^{\#} = 3.04$, $P = 0.0867$). The sex ratio in Lake Manyas was significantly male
33 dominated (sex ratio, M:F = 1.0:0.3, $\chi^2 = 44.00$; $P < 0.01$), significantly female dominated
34 in Lake Uluabat (1.0:1.5, $\chi^2 = 10.62$; $P < 0.005$), but relatively equal in Lake Sapanca

1 (1.0:1.0, $\chi^2 = 0.08$; $P = 0.78$). This pattern did not vary for the mature individuals (Lake
2 Manyas: 1.0:0.3, $\chi^2 = 42.01$; $P < 0.01$, Lake Uluabat: 1.0:2.3, $\chi^2 = 27.52$; $P < 0.01$, Lake
3 Sapanca: 1.0:1.0, $\chi^2 = 0.04$; $P = 0.834$).

4 5 *Age and growth*

6 The relationships of TL versus SL were: Lake Manyas: $TL = 1.2789SL - 0.2941$, $r = 0.99$,
7 $P < 0.01$, $n = 223$; Lake Uluabat: $TL = 1.2203SL + 0.1858$, $r = 0.97$, $P < 0.01$, $n = 575$; and
8 Lake Sapanca: $TL = 1.2261SL + 0.2227$, $r = 0.96$, $P < 0.01$, $n = 152$. Regarding length-
9 weight relationships, estimated values of b (as 95 % CI) were above 3 for Lake Uluabat
10 (positive allometry) and just below 3 for Lake Sapanca (negative allometry), but spanned
11 3.0 in Lake Manyas (isometric) (Table 3). Values of b were significantly higher in Lakes
12 Uluabat and Manyas than in Lake Sapanca ($F^\# = 11.11$, $P < 0.01$), but there was no
13 significant difference in b values between in Manyas and Uluabat lakes ($F^\# = -0.55$, $P >$
14 0.05).

15 The smallest mean LAA values were in Lake Sapanca, where minimum recorded age
16 was observed (Table 4). Greatest LAA varied with age groups (Lake Uluabat for age 1 and
17 2, and Lake Manyas for older age groups). The maximum recorded age in Lake Manyas
18 and Uluabat was 7 years (Table 4). Annual growth increments of *N. fluviatilis* in Lake
19 Manyas were considerably greater than those in other two lakes. For all study sites, growth
20 increments were mostly similar between consecutive ages, though slightly declining at
21 older ages (Fig. 2; Table 4). This resulted in significantly higher lengths at ages in Lake
22 Manyas than those in other lakes ($P^\# < 0.01$) except for ages 4 and 5 ($P^\# > 0.05$). Three
23 VGBF curves were best fitted with different t_0 and K parameter values, which both were
24 highest in Lake Manyas (Table 5). Across their range, the GI indicated the fastest growth
25 of *N. fluviatilis* in the Azov Sea, followed by Utlyusky and Bug estuaries (all native range),
26 whilst the populations of the present study had the lowest GI values that were similar to the
27 value for the non-native River Ipel population (Table 6).

28 29 *Reproduction*

30 The minimum total length and age of mature *N. fluviatilis* were: Lake Manyas: female 70
31 mm and 3 years, male 72 mm and 2 years; Lake Uluabat: female 42 mm and 2 years, male
32 68 mm and 3 years; Lake Sapanca: females 38 mm and 2 years, males 70 mm and 3 years.
33 Mean age at maturity of male *N. fluviatilis* in Lake Manyas was almost a year younger
34 earlier than in Uluabat and Sapanca lakes, whereas it was similar for females in all lakes

1 (Table 7). Length at maturity of both males and females of *N. fluviatilis* were similar in all
2 lakes, with the exception of females maturing at considerably smaller lengths in Lakes
3 Uluabat and Sapanca compared with than Lake Manyas (Table 7).

4 Although exact spawning duration could not properly have been determined due to
5 sampling frequency (i.e. seasonally), seasonal GSI values of *N. fluviatilis* in the studied
6 lakes indicated a longer spawning duration for *N. fluviatilis* in Lake Manyas (Table 7). In
7 Lake Uluabat and Sapanca, female GSI peaked in May and declined sharply in August
8 however in Lake Manyas both female and male GSI were still significantly higher in
9 August than other studied lakes (female: $F_{3,201}^{\#} = 44.58, P < 0.01$; male: $F_{3,192}^{\#} = 126.79, P$
10 < 0.01) suggesting continuing spawning but until November it appeared the spawning of
11 *N. fluviatilis* was completed in all studied lakes (Table 7). Except for August sampling in
12 Lake Manyas, gonad production was generally similar in all seasons among the lakes
13 however female GSI was significantly higher in Lake Manyas and Uluabat than Lake
14 Sapanca in May ($F_{3,167}^{\#} = 41.94, P < 0.01$) whereas the opposite was true for male GSI at
15 the same month ($F_{3,211}^{\#} = 24.06, P < 0.01$). This was also true for female *N. fluviatilis* in
16 Lake Manyas for November sampling ($F_{2,81}^{\#} = 6.95, P < 0.05$). Females had always
17 significantly higher GSI values than males ($P^{\#} < 0.05$) except for Lake Sapanca where
18 there was no significant difference between sexes in May ($t^{\#} = 0.01, P = 0.99$) and for Lake
19 Uluabat in August where males GSI were significantly higher than females ($t^{\#} = 4.38, P <$
20 0.01).

21 Mean egg diameter of *N. fluviatilis* was highest in Lake Sapanca and smallest in Lake
22 Manyas (Table 7). Mean absolute fecundity of *N. fluviatilis* varied greatly amongst the
23 lakes ($F_{2,51}^{\#} = 4.37, P < 0.05$), being higher in Manyas and Uluabat lakes than in Lake
24 Sapanca ($P < 0.01$) (Table 7). Although the same pattern was also apparent for relative
25 fecundity, the differences amongst the lakes were not significant ($F_{2,51}^{\#} = 2.59, P = 0.08$)
26 (Table 7). Fecundity was significantly ($P < 0.05$) and positively ($r > 0.90$) correlated with
27 total length and weight in all lakes studied (Table 7). Although there was no consistency
28 for faster growing populations with maturing at smaller sizes, there seemed a pattern for a
29 trade-off between smaller egg sizes and higher number of eggs (Table 7).

31 Discussion

32
33 The apparent paucity of data on the environmental biology of *N. fluviatilis* in its native and
34 the non-native range is concerning, given how it is developing invasions in Europe and the

1 invasion concern it is causing in the Great Lakes. This knowledge gap is even more
2 pronounced in its invasive range, where our extensive review of literature revealed only
3 one study from Slovakia on age and growth of the species (Plachá *et al.* 2010). Moreover,
4 the studies completed in the native range are generally relatively old and were conducted
5 in marine and brackish waters from Russia and Ukraine, limiting their utility for
6 comparisons with freshwater populations (Trifonov 1955; Bil'ko 1965; Smirnov 1986).

7 The comparable data of *N. fluviatilis* across their range suggest that their growth rates
8 are highly variable among the different geographical regions and environments. This was
9 even evident in the present study, where the three lakes were relatively close to each other
10 but still revealed high inter-population variability in all aspects of their life history traits.
11 Notably, the *N. fluviatilis* populations of these lakes were the slowest growing reported
12 from any populations, native or non-native, with this consistently the case for each
13 parameter used (growth index, growth coefficient (K) and performance (\emptyset)). Their values
14 tended to more similar to those of the only available growth data from the non-native range
15 (Plachá *et al.* 2010) than the native range. Indeed, the growth parameters of native *N.* all
16 indicated substantially faster growth rates than our study sites, perhaps a consequence of
17 their collection from marine and estuarine environments that, speculatively, could have
18 been of higher productivity and/ or had fish communities with less intense competitive
19 interactions.

20 A feature of the *N. fluviatilis* in the present study was their relatively long life spans
21 (age seven years). The exception of Lake Sapanca, where the maximum recorded age was
22 four years, with this attributed to sampling in only the littoral zone, with older and/ or
23 larger specimens being in deeper water. This is supported by the only study on growth of
24 *N. fluviatilis* previously conducted in Lake Manyas that reported substantially higher
25 length at ages, but consistent VBGF parameters (L_{∞} and K) and slope of the length-weight
26 relationship (b), compared to our data (Sasi and Berber 2010). A potential reason for the
27 different length at ages might relate to the lack of quality control in the ageing of the
28 previous study that could have resulted in low ageing precision (Beamish and MacFarlane
29 1983), and/ or from samples being collected from different areas in the lake, such as more
30 open water areas. However, the sampling locations in the lake were not revealed in that
31 study (Sasi and Berber 2010). In addition, other studies on length-weight relationships of
32 *N. fluviatilis* from different locations in native and non-native ranges of the species have
33 provided contrasting results; compared to the lakes studied here, values of b were higher in
34 the streams of the Biga peninsula from north-western Anatolia (İlhan *et al.* 2012) and non-

1 native *N. fluviatilis* in River Ipel (Plachá *et al.* 2010), but lower in River Zarrin-Gol in
2 northern Iran (Patimar *et al.* 2008). As this suggests some plasticity in aspects of *N.*
3 *fluviatilis* life history trait data, the differences in growth data between our study and Sasi
4 and Berber (2010) might also just relate to temporal variability.

5 Given the differences in growth already outlined between the freshwater and marine/
6 brackish populations of *N. fluviatilis*, the spatial differences between these systems might
7 also be a causal factor in the differences between the growth performance of the fish
8 between the three lakes. Whilst the shallow Uluabat and Manyas lakes both have very rich
9 fish faunas, they also had high abundances of the obligate predator, *E. lucius* (Çınar *et al.*
10 2013), that could have limited abundances of their prey populations and thus the weakened
11 competitive pressures for *N. fluviatilis*, facilitating their faster growth. Lake Sapanca,
12 meanwhile, had recently suffered a major drought and loss of littoral habitat, with these
13 likely to have impacted all aspects of the ecology of the *N. fluviatilis*, including their
14 forced use of spatially-restricted, sub-optimal habitats that might have increased the
15 strength of their intra- and inter-specific competitive pressures. Thus, their slow growth
16 and restricted age range in Lake Sapanca might relate to these factors and explain their
17 poor performance compared to the other two lakes. However, this must remain
18 speculative, as it was unable to be tested directly.

19 It is apparent from other studies that following sexual maturity, male *N. fluviatilis* are
20 faster growing than females in both their native (Konečná and Jurajda 2012) and non-
21 native (Plachá *et al.* 2010) populations. However, this was not a consistent finding in our
22 study, where females were significantly larger than males in Lake Manyas. This could be
23 related to more frequent presence of larger reproducing females in shorelines of Lake
24 Manyas, where they were captured significantly in higher numbers than males. This
25 preference of reproducing females could be due to higher productivity of the shorelines,
26 which was apparent with higher fecundity and gonad production as well as longer
27 spawning duration of *N. fluviatilis* females in this lake. A previous study in Lake Manyas
28 on *N. fluviatilis* (Sasi and Berber 2010) and a study from the native range of the species
29 (Bulgarian section of the River Danube; Konečná and Jurajda 2012) recorded an equal sex
30 ratio in populations, which was then considered to be a typical character of native
31 populations; indeed, male dominated goby populations are usually attributed to developing
32 non-native populations (e.g. Corkum *et al.* 2004; Gutowsky and Fox 2011). Our results
33 indicated high inter-population variability in sex ratios across the three lakes, with these
34 contrary to the pattern of equal sex ratios. These results suggest that sex ratios might be

1 more related to environmental factors rather than the species status (i.e. native or non-
2 native, e.g. Kováč, 2016). These factors might particularly relate to habitat availability for
3 spawning, where males generally are more numerous than females (Konečná and Jurajda
4 2012). Variable sex ratios in the studied lakes could also be potentially explained by the
5 newly recolonizing *N. fluviatilis* in Lake Sapanca may show an equal sex ratio, whereas
6 the species living in more stable environments in the other studied lakes could have
7 different sex ratios (e.g. Tarkan *et al.* 2012) that would also base on the sampling spots in
8 these lakes (i.e. there was some inherent bias in samples).

9 Compared to growth studies, there are even fewer studies on *N. fluviatilis* reproduction,
10 with only a single study from the non-native range found to contain data on these traits
11 (Plachá *et al.* 2010). According to this study, the species reach sexual maturity generally in
12 their second year both ranges, although it is also environmentally driven too (Pinchuk *et al.*
13 2003; Konečná and Jurajda 2012). Indeed, mean age at maturity was almost a year later in
14 *N. fluviatilis* in the present study, with the only exception for males in Lake Manyas
15 maturing at second year of life. Also, a single study from the native range of the species
16 reported that *N. fluviatilis* in Bulgarian Danube spawned in April and June (Konečná and
17 Jurajda 2012), which is line with our finding for Lake Sapanca and Lake Uluabat but not
18 for Lake Manyas where the spawning appeared to be extended to at least August (Table 7).
19 Notably, GSI values of *N. fluviatilis* in the Bulgarian Danube only matched with that in
20 Lake Sapanca but are remarkably lower than those in Lake Manyas and Lake Uluabat. In a
21 small stream in north-eastern Iran, absolute fecundity of *N. fluviatilis* varied between 276
22 and 532 eggs (mean 386 eggs) (Abdoli *et al.* 2002), and from a mountain river in northern
23 Iran, mean absolute and relative fecundity values were 508 eggs and 61 eggs g⁻¹ (Patimar
24 *et al.* 2008). These values are also quite different to our data from the three lakes, where
25 the relative fecundity values suggested higher egg production in the lakes. The
26 significantly lower egg and gonad production of *N. fluviatilis* in Lake Sapanca compared to
27 Lakes Uluabat and Manyas could have related to the habitat loss and sub-optimal habitats
28 outlined above. As a habitat specialist, *N. fluviatilis* is known to inhabit shorelines with
29 sandy gravel bottoms (e.g. Čápoová *et al.* 2008), with these completely lost in Lake Sapanca
30 due to drought and abstraction. Another reason for lower egg and gonad production of *N.*
31 *fluviatilis* in Lake Sapanca would be the relatively low productivity of the lake compared
32 to eutrophic Uluabat and Manyas lakes (Table 1), as was also the case for other fishes,
33 such as roach *Rutilus rutilus* and rudd *Scardinius erythrophthalmus* in Lake Sapanca
34 (Tarkan 2006). Higher productivity of two studied shallow lakes could also explain the

1 marked difference in absolute and relative fecundity values as well as in gonad production,
2 with presumably less productive lotic environments in Iran (Abdoli *et al.* 2002; Patimar *et*
3 *al.* 2008). However, higher egg production was observed to be compensated by smaller
4 egg sizes in the studied lakes that could be attributed to trade-off between these two traits
5 (i.e. egg number and size, e.g. Copp *et al.* 2010). With a caveat for small number of
6 comparable habitats, the differences observed between reproductive features (e.g.
7 fecundity and size at maturity) and growth of native and non-native *N. fluviatilis* were not
8 in accordance with one of the main characteristics considered for invading specimens, such
9 as the allocation of more resources into reproduction than somatic growth (e.g. Kováč *et*
10 *al.* 2009).

11

12 **Conclusion**

13 Overall, our results suggest that irrespective of their native/ non-native status, *N. fluviatilis*
14 can display high biological plasticity, depending on the environment in which they are
15 present. The species should thus be considered as one where phenotypic plasticity is a key
16 factor in its establishment success (e.g. Kováč, 2016). Observed attributes such as
17 generalist life history, plasticity in growth and capability of shifting reproductive features
18 tend to be advantageous for introduced fishes, as they facilitate their colonisation of new
19 habitats and ecosystems (i.e. Colautti *et al.* 2006). Although *N. fluviatilis* does not spread
20 as fast as other invasive gobies such as *N. melanostomus* (Zahorska *et al.* 2013) and *P.*
21 *kessleri* (Copp *et al.* 2005), it is continuing to expand its non-native European distribution
22 range (Plachá *et al.* 2010) and is still considered one of the most important potential
23 invaders in the near future for North America (Pagnucco *et al.* 2015) by following the
24 same pathways as other Ponto-Caspian species (e.g. Kornis *et al.* 2012). Regardless, this
25 study provides important baseline information on the basic biological features of *N.*
26 *fluviatilis* in its native range that has utility for understanding their establishment and
27 dispersal success in their non-native range. This information is particularly expected to fill
28 the gap for comparative studies on growth and life history traits between native and non-
29 native populations of the species for better understanding its invasion potential.

30

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32

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4 5 **Conflicts of interest**

6 The authors declare no conflict of interest

7 8 **References**

9 Abdoli, A., Rahmani, H., and Rasooli, P. (2002). On the occurrence, diet and reproduction
10 of *Neogobius fluviatilis* in Madarsoo stream, Golestan National Park (north eastern
11 Iran). *Zoology in the Middle East* **26**, 123–128.

12 Albay, M., and Akçaalan, R. (2003). Comparative study of periphyton colonisation on
13 common reed (*Phragmites australis*) and artificial substrate in a shallow lake, Manyas,
14 Turkey. *Hydrobiologia* **506/509**, 531–540.

15 Albay, M., and Akçaalan, R. (2008). Effects of water quality and hydrologic drivers on
16 periphyton colonization on *Sparganium erectum* in two Turkish lakes with different
17 mixing regimes. *Environmental Monitoring and Assessment* **146**, 171–181.

18 Almeida, D., Ribeiro, F., Leunda, P.A., Vilizzi, L., and Copp, G. H. (2013). Effectiveness
19 of FISK, an invasiveness screening tool for non-native freshwater fishes, to perform risk
20 identification assessments in the Iberian Peninsula. *Risk Analysis* **33**, 1404–1413.

21 Anderson, M. J., and Robinson, J. (2001). Permutation tests for linear models. *Australian
22 and New Zealand Journal of Statistics* **43**, 75–88.

23 Anderson, M. J., Gorley, R. N., and Clarke, K. R. (2008). ‘PERMANOVA+ for PRIMER:
24 Guide to Software and Statistical Methods’. (PRIMER-E Ltd, Plymouth, UK.).

25 Arman, H., Ileri, R., Dogan, E., and Eren, B. (2009). Investigation of Lake Sapanca water
26 pollution, Adapazari, Turkey. *International Journal of Environmental Studies* **66**, 547–
27 561.

28 Arslan, N., Ayık, Ö., and Şahin, Y. (2010). Diversity and structure of Chironomidae
29 (Diptera) limnofauna of Lake Uluabat, a Ramsar site of Turkey, and their relation to
30 environmental variables. *Turkish Journal of Fisheries and Aquatic Sciences* **10**, 315–
31 322.

32 Beamish, R., and McFarlane, G.A. (1983). The forgotten requirement for age validation in
33 fisheries biology. *Transactions of the American Fisheries Society* **112**, 735–743.

- 1 Bagenal, T. B., and Tesch, F. W. (1978). Age and growth. In 'Methods for Assessment of
2 Fish Production in Fresh Waters'. (Ed T. B. Bagenal.) pp. 101–136. (IBH Handbook,
3 Blackwell Scientific Publications, Oxford, UK.).
- 4 Biľko, V. P. (1965). Rost byčka piesočníka v Dneprovsko-Bugskom limane [The growth
5 of the sand goby in them Dnieper-Bug estuary]. *Gidrobiol. Zh.* **1**, 56–60 [in Russian].
- 6 Britton, J. R., Harper, D. M., and Oyugi, D. O. (2010). Is the fast growth of an equatorial
7 *Micropterus salmoides* population explained by high water temperature? *Ecology of*
8 *Freshwater Fish* **19**, 228–238.
- 9 Britton, J. R., Copp, G. H., and Gozlan, R. E. (2011). Managing non-native fish in the
10 environment. *Fish and Fisheries* **12**, 256–274.
- 11 Burnham, K. P., and Anderson, D. R. (2003). 'Model Selection and Multimodel Inference:
12 a Practical Information-theoretic Approach'. (Springer, New York.).
- 13 Čápková, M., Zlatnická, I., Kovač, V., and Katina, S. (2008). Ontogenetic variability in the
14 external morphology of monkey goby, *Neogobius fluviatilis* (Pallas, 1814) and its
15 relevance to invasion potential. *Hydrobiologia* **607**, 17–26.
- 16 Colautti, R. I., Grigorovich, I. A., and MacIsaac, H. J. (2006). Propagule pressure: A null
17 model for biological invasions. *Biological Invasions* **8**, 1023–1037.
- 18 Copp, G. H., Vilizzi, L., Tidbury, H., Stebbing, P. D., Tarkan, A. S., Miossec, L., and
19 Gouletquer, P. (2016). Development of a generic decision-support tool for identifying
20 potentially invasive aquatic taxa: AS-ISK. *Management of Biological Invasions* **7**, 343–
21 350.
- 22 Copp, G. H., Tarkan, A. S., Godard, M. J., Edmonds N. J., and Wesley K. J. (2010).
23 Preliminary assessment of feral goldfish impacts on ponds, with particular reference to
24 native crucian carp. *Aquatic Invasions* **5**, 413–422.
- 25 Copp, G. H., Bianco, P. G., Bogutskaya, N., Erős, T., Falka, I., Ferreira, M. T., Fox, M. G.,
26 Freyhof, J., Gozlan, R. E., Grabowska, J., Kováč, V., Moreno-Amich, R., Naseka, A.
27 M., Peňáz, M., Povž, M., Przybylski, M., Robillard, M., Russell, I. C., Stakėnas, S.,
28 Šumer, S., Vila-Gispert, A., and Wiesner, C. (2005). To be, or not to be, a non-native
29 freshwater fish? *Journal of Applied Ichthyology* **21**, 242–262.
- 30 Corkum, L. D., Sapota, M. R., and Skorá, K. E. (2004). The round goby, *Neogobius*
31 *melanostomus*, a fish invader on both sides of the Atlantic Ocean. *Biological Invasions*
32 **6**, 173–181.
- 33 Çınar, Ş., Küçükbara, R., Balık, İ., Çubuk, H., Ceylan, M., Erol, K. G., Yeğen, V., and
34 Bulut, C. (2013). Uluabat (Apolyont) Gölü'ndeki balık faunasının tespiti, tür

- 1 kompozisyonu ve ticari avcılığın türlere göre dağılımı [Detection of fish fauna, species
2 composition and distribution of commercial fishing according to species in Lake
3 Uluabat]. *Journal of Fisheries Sciences.com* **7**, 309–316. [in Turkish].
- 4 Davidson, A. M., Jennions, M., and Nicotra, A. B. (2011). Do invasive species show
5 higher phenotypic plasticity than native species and, if so, is it adaptive? A meta-
6 analysis. *Ecology letters* **14**, 419–431.
- 7 DeMaster, D. P. (1978). Calculation of the average age of sexual maturity in marine
8 mammals. *Journal of the Fisheries Research Board of Canada* **35**, 912–915.
- 9 Francis, R. I. C. C. (1990). Back-calculation of fish length: a critical review. *Journal of*
10 *Fish Biology* **36**, 883–902.
- 11 Froese, R., and Pauly, D. Editors. (2017). ‘FishBase. World Wide Web electronic
12 publication.’ Available at <http://www.fishbase.org> [accessed 15 September 2017].
- 13 Geldiay, R., and Balık, S. (2009). ‘Türkiye Tatlısu Balıkları.’ [The Freshwater Fishes of
14 Turkey.] (Ege Üniversitesi Fen Fakültesi Kitaplar Serisi, İzmir, Turkey.) [In Turkish].
- 15 Gozlan, R. E., Britton, J. R., Cowx, I. G., and Copp, G. H. (2010). Current knowledge on
16 non-native freshwater fish introductions. *Journal of Fish Biology* **76**, 751–786.
- 17 WWF (2015). ‘Sapanca Gölü’nde Su Riski ve Yönetimi Raporu’ [Report on Water Risk
18 and Economy in Lake Sapanca]. WWF Turkey, İstanbul, Turkey [In Turkish].
- 19 Grabowska, J., and Grabowski, M. (2005). Diel-feeding activity in early summer of racer
20 goby *Neogobius gymnotrachelus* (Gobiidae): a new invader in Baltic basin. *Journal of*
21 *Applied Ichthyology* **21**, 282–286.
- 22 Grabowska, J., Grabowski, M., and Kostecka, A. (2009). Diet and feeding habits of
23 monkey goby (*Neogobius fluviatilis*) in a newly invaded area. *Biological Invasions* **11**,
24 2161–2170.
- 25 Gutowsky, L. F. G., and Fox, M. G. (2011). Occupation, body size and sex ratio of round
26 goby (*Neogobius melanostomus*) in established and newly invaded areas of an Ontario
27 river. *Hydrobiologia* **671**, 27–37.
- 28 Hickey, P., and Dexter F. K. (1979). A comparative index of quantifying growth in length
29 of fish. *Fisheries Management* **10**, 147–151.
- 30 İlhan, A., Sarı, H. M., Saygı, H., and Ustaoglu, M. R. (2012). Length–weight relationships
31 of freshwater fishes in the Biga Peninsula (northwestern Anatolia, Turkey). *Journal of*
32 *Applied Ichthyology* **28**, 857–858.

- 1 Jakšić, G., Jadan, M., and Piria, M. (2016). The review of ecological and genetic research
2 of Ponto-Caspian gobies (Pisces, Gobiidae) in Europe. *Croatian Journal of Fisheries*
3 **74**, 93–114.
- 4 Jakovlić, I., Piria, M., Šprem, N., Tomljanović, T., Matulić, D., and Treer, T. (2015).
5 Distribution, abundance and condition of invasive Ponto-Caspian gobies *Ponticola*
6 *kessleri* (Günther, 1861), *Neogobius fluviatilis* (Pallas, 1814), and *Neogobius*
7 *melanostomus* (Pallas, 1814) in the Sava River basin, Croatia. *Journal of Applied*
8 *Ichthyology* **31**, 888–894.
- 9 Kakareko, T., Żbikowski, J., and Żytkowicz, J. (2005). Diet partitioning in summer of two
10 syntopic neogobiids from two different habitats of the lower Vistula River, Poland.
11 *Journal of Applied Ichthyology* **21**, 292–295.
- 12 Karafistan, A., and Arik-Çolakoğlu, F. (2005). Physical, chemical and microbiological
13 water quality of the Manyas Lake. *Mitigation and Adaptation Strategies for Global*
14 *Change* **10**, 1–17.
- 15 Konečná, M., and Jurajda, P. (2012). Population structure, condition, and reproduction
16 characteristics of native monkey goby, *Neogobius fluviatilis* (Actinopterygii:
17 Perciformes: Gobiidae), in the Bulgarian Danube. *Acta Ichthyologica et Piscatoria* **42**,
18 321–327.
- 19 Kornis, M. S., Mercado-Silva, N., and Vander Zanden, M. J. (2012). Twenty years of
20 invasion: a review of round goby *Neogobius melanostomus* biology, spread and
21 ecological implications. *Journal of Fish Biology* **80**, 235–285.
- 22 Kováč, V. (2016). The fish itself, not only environment, should be considered in studying
23 invasion success. *Ecology of Freshwater Fish* **25**, 674–677.
- 24 Kováč, V., Copp, G. H., and Sousa, R. P. (2009). Life-history traits of invasive bighead
25 goby *Neogobius kessleri* from the middle Danube with a reflection of who may win the
26 goby competition. *Journal of Applied Ichthyology* **25**, 33–37.
- 27 Magnin, G., and Yazar, M. (1997). ‘Important Bird Nesting Sites of Turkey.’ (Society for
28 Protection of Nature-DHKD, İstanbul, Turkey).
- 29 Mastitsky, S. E., Karatayev, A. Y., Burlakova, L. E., and Adamovich, B. V. (2010). Non-
30 native fishes of Belarus: diversity, distribution, and risk classification using the Fish
31 Invasiveness Screening Kit (FISK). *Aquatic Invasions* **5**, 103–114.
- 32 Numann, W. (1958). ‘Anadolu’nun Muhtelif Göllerinde Limnolojik ve Balıkçılık İlmi
33 Bakımından Araştırmalar ve Bu Göllerde Yaşayan Sazanlar Hakkında Özel Bir Etüt’
34 [Research on Limnological and Fishery Sciences in Various Lakes of Anatolia and a

- 1 Special Study on Common Carp Living in These Lakes]. Monography from İstanbul
2 University Science Faculty Hydrobiology Research Institute No: 7, İstanbul [in
3 Turkish].
- 4 Ogle, D. H. (2017). 'FSA: Fisheries Stock Analysis. R package version 0.8.16'.
- 5 Oyugi, D. O., Cucherousset, J., Ntiba, M. J., Kisia, S. M., Harper, D. M., and Britton, J. R.
6 (2011). Life history traits of an equatorial common carp *Cyprinus carpio* population in
7 relation to thermal influences on invasive populations. *Fisheries Research* **110**, 92–97.
- 8 Pagnucco, K. S., Maynard, G. A., Fera, S. A., Yand, N. D., Nalepa, T. F., and Ricciardi, A.
9 (2015). The future of species invasions in the Great Lakes-St. Lawrence River basin.
10 *Journal of Great Lakes Research* **41**, 96–107.
- 11 Pauly, D., and Munro, J. L. (1984). Once more on the comparison of growth in fish and
12 invertebrates. *Fishbyte* **2**, 21.
- 13 Patimar, R., Mahdavi, M.J., and Adineh, H. (2008). Biology of sand goby *Neogobius*
14 *fluviatilis pallasii* (Berg, 1916) in Zarrin-gol river (East Alborz mountain). *Journal of*
15 *Agricultural Sciences and Natural Resources* **15**, 54–64.
- 16 Patzner, R. A., Van Tassell, J. L., Kovačić, M., and Kapoor, B. G. (2011). 'The Biology of
17 Gobies.' (Enfield, NH: Science Publishers).
- 18 Pinchuk, V. I., Vasil'eva, E. D., Vasil'ev, V. P., and Miller, P. (2003). *Neogobius*
19 *gymnotrachelus* (Kessler, 1857). In 'The Freshwater Fishes of Europe, vol 8/I
20 Mugilidae, Atherinidae, Atherionopsidae, Blenniidae, Odontobutidae, Gobiidae'. (Ed P.
21 J. Miller.) pp. 264–2791. (Wiesbaden: AULA-Verlag.)
- 22 Piria, M., Jakšić, G., Jakovlić, I., and Treer, T. (2016a). Dietary habits of invasive Ponto-
23 Caspian gobies in the Croatian part of the Danube River basin and their potential impact
24 on benthic fish communities. *Science of Total Environment*, **540**, 386–395.
- 25 Piria, M., Povz, M., Vilizzi, L., Zanella, D., Simonović, P., and Copp, G. H. (2016b). Risk
26 screening of non-native freshwater fishes in Croatia and Slovenia using FISK (Fish
27 Invasiveness Screening Kit). *Fisheries Management and Ecology* **23**, 21–31.
- 28 Plachá, M., Balážová, M., Kováč, V., and Katina, S. (2010). Age and growth of non-native
29 monkey goby *Neogobius fluviatilis* (Teleostei, Gobiidae) in the River Ipel', Slovakia.
30 *Folia Zoologica* **59**, 332–340.
- 31 Puntila, R., Vilizzi, L., Lehtiniemi, M., and Copp G. H. (2013). First application of FISK
32 the freshwater Fish Invasiveness Screening Kit in Northern Europe: example of
33 Southern Finland. *Risk Analysis* **33**, 1397–1403.

- 1 R Core Team (2017). 'R: A language and environment for statistical computing'. (R
2 Foundation for Statistical Computing, Vienna, Austria).
- 3 Ribeiro, F., Elvira, B., Collares-Pereira, M. J. and Moyle, P. B. (2008). Life-history traits
4 of non-native fishes in Iberian watersheds across several invasion stages: a first
5 approach. *Biological Invasions* **10**, 89–102.
- 6 Ricker, W. E. (1975). Computation and interpretation of biological statistics of fish
7 populations. *Bulletin of the Fisheries Research Board of Canada* **191**, 382.
- 8 Sasi, H., and Berber, S. (2010). Some biological characteristics of monkey goby in
9 Anatolia. *Asian Journal of Animal and Veterinary Advances* **5**, 229–233.
- 10 Simberloff, D., Martin, J. L., Genovesi, P., Maris, V., Wardle, D. A., Aronson, J.,
11 Courchamp, F., Galil, B., García-Berthou, E., Pascal, M. and Pyšek, P. (2013). Impacts
12 of biological invasions: what's what and the way forward. *Trends in Ecology &*
13 *Evolution* **28**, 58–66.
- 14 Simonović, P., Tošić, A., Vassilev, M., Apostolou, A., Mrdak, D., Ristovska, M., Kostov,
15 V., Nikolić, V., Škraba, D., Vilizzi, L., and Copp, G. H. (2013). Risk identification of
16 non-native freshwater fishes in four countries of the Balkans Region using FISK.
17 *Mediterranean Marine Science* **14**, 369–376.
- 18 Smirnov, A. N. (1986). 'Fauna Ukrainy 8, Ryby (5): Okuneobraznye (byčkovidnyje),
19 skorpenoobraznyje, kambaloobraznyje, udiljščikoobraznyje [Fauna Ukrainy 8, Fishes:
20 Perciformes (Gobioidei), Scorpaeniformes, Pleuronectiformes, Lophiiformes]'.
21 (Naukova Dumka, Kiev). [in Russian].
- 22 Tarkan, A. S. (2006). Reproductive ecology of two cyprinid fish in an oligotrophic lake
23 near the southern limits of their distribution range. *Ecology of Freshwater Fish* **15**, 131–
24 138.
- 25 Tarkan, A. S., Copp, G. H., Top, N., Özdemir, N. Önsoy, B., Bilge, G., Filiz, H., Yapıcı,
26 S., Ekmekçi, G., Kırankaya, S., Emiroğlu, O., Gaygusuz, Ö., Gürsoy Gaygusuz, C.,
27 Oymak, A., Özcan, G. and Saç, G. (2012). Are introduced gibel carp *Carassius gibelio*
28 in Turkey more invasive in artificial than in natural waters? *Fisheries Management and*
29 *Ecology* **19**, 178–187.
- 30 Tarkan, A. S., Karakuş, U., Tepeköy, E. G., Top, N., Yalçın-Özdilek, Ş., Partal, N., and
31 Britton, J. R. (2018). Trophic interactions of two Ponto-Caspian gobies in the Turkish
32 part of their native range. *Turkish Journal of Fisheries and Aquatic Sciences* (in press).
- 33 Thacker, C. E., and Roje, D. M. (2011). Phylogeny of Gobiidae and identification of
34 gobiid lineages. *Systematics and Biodiversity* **9**, 329–347.

- 1 Trifonov, G. P. (1955). Biologia razmnoženija azovskich byčkov [Breeding biology of the
2 Azov gobies]. *Tr. Karadag. Biol. Sta. AN USSR* **13**, 5–47 [in Russian].
- 3 Trippel, E. A., and Harvey, H. H. (1987). Reproductive responses of five white sucker
4 (*Catostomus commersoni*) populations in relation to lake acidity. *Canadian Journal of*
5 *Fisheries and Aquatic Sciences* **44**, 1018–1023.
- 6 Vilizzi, L., Copp, G. H., and Britton, J. R. (2013). Age and growth of European barbel
7 *Barbus barbus* (Cyprinidae) in the small, mesotrophic River Lee and relative to other
8 populations in England. *Knowledge and Management of Aquatic Ecosystems* **9**, 409.
- 9 Vilizzi, L., Ekmekçi, F. G., Tarkan, A. S, and Jackson, Z. (2015). Growth of common carp
10 *Cyprinus carpio* in Anatolia (Turkey), with a comparison to native and invasive areas
11 worldwide. *Ecology of Freshwater Fish* **24**, 165–180.
- 12 Walford, L. A. (1946). A new graphic method of describing the growth of animals.
13 *Biological Bulletin of the Marine Biology Laboratory, Woods Hole* **90**, 141–147.
- 14 Wootton, R. J. (1990). ‘Ecology of Teleost Fishes’. Kluwer Academic Publishers, London.
- 15 Zahorska, E., Svolikova, K., and Kovac, V. (2013). Do invasive populations of topmouth
16 gudgeon (*Pseudorasbora parva*, Temminck and Schlegel) from disturbed and
17 undisturbed habitats follow different life-histories? *International Review of*
18 *Hydrobiology* **98**, 61–70.
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1 **Tables**

2 **Table 1.** Latitude (Lat), longitude (Lon), surface area (SA, km²), altitude (Alt, m), minimum (Min), maximum (Max) and mean Temperature
3 (°C), mean and maximum depth (m), pH, dissolved oxygen (DO, mg⁻¹), electrical conductivity (EC, μS cm⁻¹), total phosphorus (TP, μg⁻¹) and
4 total nitrogen (TN, mg⁻¹) of three lakes in Marmara Region where *Neogobius fluviatilis* were sampled.

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Lake	Lat	Lon	SA	Alt	Temperature			Depth		pH	DO	EC	TP	TN
					Min	Max	Mean	Mean	Max					
Manyas	40°12'	27°56'	178	18	7.1	27.1	18.6	1.5	3.6	8.1	8.5	2830	628	0.83
Sapanca	40°42'	30°15'	47	30	8.4	27.5	15.8	26.0	55.0	8.9	9.4	253	12	1.96
Uluabat	40°10'	28°35'	136	9	4.1	28.9	18.1	2.5	4.5	8.3	8.0	553	179	9.19

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Table 2. Number of specimens (n), minimum (Min), maximum (Max), mean and standard deviation (SD) of total length (TL) and weight (W) of male (M) and female (F) *Neogobius fluviatilis* from Sapanca, Uluabat and Manyas lakes.

Lakes	n	TL				W			
		Min	Max	Mean	SD	Min	Max	Mean	SD
Manyas (M)	132	34	173	136.15	2.92	0.31	81.71	43.08	18.77
Manyas (F)	44	25	130	58.64	2.89	0.20	35.26	4.26	6.29
Uluabat (M)	124	55	143	88.62	1.87	1.87	36.32	8.93	5.82
Uluabat (F)	181	44	120	74.53	1.23	1.21	21.49	5.10	3.00
Sapanca (M)	62	31	107	62.45	1.53	0.24	12.35	2.69	2.31
Sapanca (F)	65	42	81	58.49	0.98	0.65	5.92	2.14	1.17

Table 3. Parameter estimates (with 95% lower and upper confidence intervals: LCI and UCI, respectively) for the length-weight (WL) relationships for *Neogobius fluviatilis* in Manyas, Uluabat and Sapanca lakes.

WL				
Parameter	Estimate	SE	LCI	UCI
Manyas				
<i>a</i>	0.000015	0.000006	0.000007	0.000032
<i>b</i>	3.009	0.082	2.855	3.169
Uluabat				
<i>a</i>	0.000008	0.00001	0.000006	0.000011
<i>b</i>	3.067	0.031	3.001	3.128
Sapanca				
<i>a</i>	0.000014	0.000003	0.000010	0.000020
<i>b</i>	2.907	0.041	2.825	2.989

Table 4. For *Neogobius fluviatilis* (all individuals combined) from three lakes in the Marmara region, number of specimens (n), mean total length (TL) in mm at capture, mean back-calculated lengths at age, standard error (SE), and mean annual growth increments using the scale radius to TL regression equation.

		Back-calculated body lengths at age															
		TL at capture		Age 1		Age 2		Age 3		Age 4		Age 5		Age 6		Age 7	
Manyas	n	TL	SE	TL	SE	TL	SE	TL	SE	TL	SE	TL	SE	TL	SE	TL	SE
2015	2	39.6	0.05	29.20	0.05												
2014	3	53.5	0.18	28.30	0.09	33.57	0.13										
2013	10	71.1	0.35	44.20	0.06	59.33	0.08	74.60	0.08								
2012	11	78.1	0.16	41.00	0.10	52.59	0.16	65.40	0.16	77.50	0.16						
2011	6	95.5	0.63	44.60	0.29	58.24	0.43	71.30	0.45	86.90	0.66	98.20	0.77				
2010	2	125.0	0.50	51.80	0.34	66.91	0.32	83.50	0.46	100.80	0.46	115.90	0.67	125.00	0.65		
2009	1	130.0	-	42.80	-	59.93	-	73.90	-	88.00	-	100.40	-	116.00	-	130.00	-
		Mean back-calculated TL at age		40.28	0.32	55.11	0.47	73.72	0.29	88.27	0.48	104.80	0.56	120.40	0.45	130.00	-
		Mean TL increment (mm)			14.83		18.61		14.55		16.53		15.60		9.60		
Uluabat																	
2015	4	36.25	0.26	39.00	0.40												
2014	10	56.30	0.13	43.50	0.12	56.48	0.18										
2013	47	69.30	0.09	44.38	0.10	58.61	0.15	71.60	0.20								
2012	40	88.60	0.19	42.70	0.10	55.26	0.15	67.71	0.20	79.91	0.24						
2011	22	97.70	0.29	42.97	0.08	55.96	0.12	69.87	0.15	83.48	0.19	95.50	0.20				
2010	13	104.70	0.26	40.44	0.12	53.47	0.12	66.25	0.14	79.65	0.18	91.45	0.21	103.95	0.22		
2009	3	113.00	0.37	42.32	0.02	55.53	0.13	67.15	0.09	78.37	0.02	89.99	0.04	102.82	0.13	113.66	0.37
		Mean back-calculated TL at age		42.24		55.89		68.52		80.36		92.33		103.39		113.67	-
		Mean TL increment (mm)			13.65		12.63		11.84		11.97		11.06		10.28		
Sapanca																	
2015	0	0.00	-	-	-												
2014	13	51.07	0.16	4.02	0.13	5.11	0.16										
2013	16	61.62	0.25	4.00	0.13	5.11	0.16	6.16	0.25								
2012	8	72.62	0.16	3.97	0.08	5.09	0.14	6.19	0.19	7.26	0.16						
		Mean back-calculated TL at age		39.96	0.16	51.02	0.05	61.75	0.12	72.63	-						
		Mean TL increment (mm)			11.06		10.73		10.87								

Table 5. Growth in *Neogobius fluviatilis* in three lakes of natural range of distribution (see Fig. 1) as described by the von Bertalanffy growth function (VBGF). For each model parameter estimates are provided with SE (standard errors) and 95% lower and upper confidence intervals (LCI and UCI, respectively; 1000 bootstrap iterations) for best fit models. TL_{∞} = asymptotic total length (mm); K = Brody growth coefficient (years^{-1}); t_0 = age of the fish at 0 mm TL. Statistically significant tests (in bold) are Bonferroni-corrected at $\alpha = 0.05/5 = 0.01$ because five models were derived from the same dataset (or subsets thereof). *M*: Manyas. *U*: Uluabat. *S*: Sapanca.

Parameter	Estimate	SE	LCI	UCI	t	P
TL_{∞}	254.88	186.27	136.65	736.37	1.37	0.173
K_M	0.26	0.11	0.03	0.33	0.93	0.354
K_U	0.06	0.06	0.02	0.18	0.92	0.360
K_S	0.06	0.06	0.02	0.20	0.99	0.322
t_{0M}	0.26	0.68	-0.67	1.16	0.37	0.710
t_{0U}	-3.50	1.46	-5.13	-1.49	-2.41	0.017
t_{0S}	-1.59	1.27	-5.78	0.04	-1.25	0.212

Table 6. Mean length at age (total length: TL, mm), growth index (GI), parameters of von Bertalanffy growth function (L_{∞} , K) and growth performance (\emptyset) of female (F), male (M) and combined (F + M) *Neogobius fluviatilis* from various ecosystems (river, lake, estuary and sea) in native (N) and introduced (I) distribution range. A = Age.

Location (status)	Sex	A1	A2	A3	A4	A5	A6	A7	GI	L_{∞} (mm)	K (year ⁻¹)	\emptyset	Reference
River Ipel (I)	F	50	64	73	90				62	96	0.30	3.44	Placha <i>et al.</i> (2010)
	M	52	62	77	98	124			64	132	0.23	3.60	Placha <i>et al.</i> (2010)
Dnieper Estuary (N)	F	73	100	134					102	166	0.52	4.16	Bil'ko (1965)
	M	74	125	138					112	142	1.36	4.44	Bil'ko (1965)
Bug Estuary (N)	F	87	126	145					119	161	0.77	4.30	Bil'ko (1965)
	M	90	137	144					124	145	1.87	4.67	Bil'ko (1965)
Azov Sea (N)	F	105	134						121	140	1.89	4.57	Trifonov (1955)
	M	128	161						147	171	1.44	4.62	Trifonov (1955)
Utlyusky Estuary (N)	F+M	115	130						125	132	2.09	4.56	Smirnov (1986)
Lake Manyas (N)	F+M	75	109	128	138	149			104	228	0.49	4.41	Sasi and Berber (2010)
Lake Manyas (N)	F+M	40	55	73	88	105	120	140	56	255	0.26	4.23	Present study
Lake Uluabat (N)	F+M	42	56	69	80	92	104	114	56	255	0.06	3.59	Present study
Lake Sapanca (N)	F+M	40	51	62	73				51	255	0.06	3.59	Present study

Table 7. Mean at age maturity (AaM, in years), mean total length (TL) at maturity (TLaM, in mm), mean absolute (AF) and relative fecundity (RF), mean egg diameter (ED, in mm), relationship between TL and weight (W) and absolute fecundity, and Gonadosomatic Index (GSI) of *Neogobius fluviatilis* from Manyas, Uluabat and Sapanca lakes. M = males, F = females. Number of specimens used for the calculation of each variable is given in parentheses. See Material and Methods for the number of specimens and eggs for fecundity and egg diameter calculations. Total length range (TL, mm) of the specimens that mean fecundity and egg diameter were calculated: Lake Manyas = 72-130, Lake Uluabat = 57-101, Lake Sapanca = 45-80.

Reproductive parameters	Manyas	Uluabat	Sapanca
AaM (M)	2.50 (40)	3.88 (47)	3.20 (37)
AaM (F)	3.36 (41)	3.77 (65)	3.00 (35)
TLaM (M)	77.8 (40)	71.7 (59)	71.7 (40)
TLaM (F)	71.4 (61)	47.0 (84)	40.0 (53)
AF	535.74±446.68	436.46±215.95	170.44±51.15
RF	144.45±138.01	98.74±31.69	73.28±26.58
ED	0.35±0.30	0.40±0.22	0.57±0.28
TL-AF	0.4201AF ^{1.4635}		1.1008AF ^{0.3392}
W-AF	0.0007AF ^{1.4404}	1.8253AF ^{0.2302}	0.0081AF ^{1.1242}
		0.0303AF ^{0.8241}	
GSI – August (M)	5.46±1.42	1.08±0.45	0.98±0.46
GSI – August (F)	13.57±5.21	0.26±0.29	1.12±1.01
GSI – November (M)	1.00±1.03	0.34±0.27	0.35±0.19
GSI – November (F)	3.65±5.98	0.90±0.66	0.88±0.28
GSI – January (M)	0.95±0.28	0.75±0.74	1.02±0.23
GSI – January (F)	1.96±0.35	1.10±0.59	2.14±0.45
GSI – May (M)	1.24±1.25	1.91±1.64	5.84±7.54
GSI – May (F)	16.10±5.39	17.13±8.15	5.83±6.83

Figure captions

Fig. 1. Lakes where *Neogobius fluviatilis* were sampled in Marmara region (northwest Turkey).

Fig. 2. Growth in length for *Neogobius fluviatilis* as described by the von Bertalanffy growth function (VBGF; parameters in Table 5) fitted by lake. In the scatterplots, each point represents one mean length-at-age (LAA). The points in the scatterplot are slightly jittered to improve visibility.